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Determination of Imaging Sensor Line Spread Function Through The
Eigentarget Test Method

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ABSTRACT

Determination of the Modulation Transfer Function (MTF) of an imaging system can be tedious and laborious when done by conventional means. However, through clever manipulation of test imagery, the Line Spread Function (LSF) and hence the MTF can be more easily found. This paper will introduce a new data reduction approach which is a viable candidate as a new metric for testing imaging systems in the field. The repeatability and objectivity of this analysis appears to have great potential utility.

Keywords: Modulation Transfer Function, Line Spread Function, slit target test, System Under Test, Eigentarget, concavity, measured response, actual spatial response, triangle wave

1. CONVENTIONAL DETERMINATION OF THE LINE SPREAD FUNCTION

One way of determining the MTF of an imaging system is through finding its LSF. This can be done by several methods; one of which is the slit target test. In theory, the slit target test is desirable by virtue of the fact that a slit represents an impulse in the dimension of interest. However, in practice compromises must be made. Even if it were physically possible to construct a target which satisfies the definition of an impulse generating slit, one would then be faced with the insurmountable problem of getting enough energy through the target to sufficiently stimulate the System Under Test (SUT) so that the line LSF can be measured. So, in practice trade-offs must be made. And that is not the end of the issue. When analyzing the resulting data, one must then account for the spatial content of the target which was used, as illustrated in equations (1) and (2).

$$H_M(\nu) = H_t(\nu) H_s(\nu) H_a(\nu) \quad (1)$$

or:

$$H_s(\nu) = \frac{H_M(\nu)}{H_t(\nu) H_a(\nu)}$$

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Where:

$H_s(\nu)$ is the MTF of the SUT

$H_M(\nu)$ is the MTF measured spatial frequency response of the SUT,

$H_t(v)$ is the spatial content of the slit target,

$H_a(v)$ is the MTF of the data acquisition system*.

* For the purposes of this paper we will assume this to be 1.

2. THE EIGENTARGET

Suppose the target in question is of variable width and is adjusted so that the slit subtends several pixels of the SUT. Under these conditions the SUT "sees" the full intensity swing from background to target, i.e. state 1 and state 2 with a number of pixels defining the transition pixels between state 1 and state 2 and then from state 2 to state 1. Now, if we begin to narrow the width of the slit, fewer and fewer pixels will be at state 2. At some point, the dimensions of the slit will be such that only one state 2 pixel remains. This condition could then be described as the Eigentarget dimension. One may then ask the question: Could the same response be found by simply truncating the data taken under the original conditions described above?

2.1 INTERPRETING THE TRUNCATED DATA

Having collected data taken with a target of dimensions such that the target subtends several pixels of the SUT, the next step is to truncate the data profile so that it emulates the system response to the Eigentarget and then calculate the MTF of the SUT. It is accepted by many that the MTF for an incoherent imaging system may be described as a sinc-squared function. Given that assumption for the moment, the task at hand is to scale the assumed sinc-squared function appropriately. In order to do this we must first account for the spatial content of the Eigentarget. The first step then is to examine the response data which we have synthesized. Inspection of actual data from a staring Charge Coupled Device (CCD) (Figure 1) reveals some interesting nuances. Were it not for the spatial content contributed by the target, one would expect the waveform to ramp linearly from state 1 to state 2 and back to state 1, which would be consistent with the Fourier transform of a sinc-squared function. Instead, we find that the data profile as we follow it from state one to state two begins concave up. As the data profile approaches state two, it becomes concave down, suggesting a third order function. We also note that the concavity appears to be fairly symmetrical and that the second half of the response curve (state 2 to state one) is a reasonable mirror image of the first. Noting that the measured data is the convolution of the response of the SUT with a square wave that is the Eigentarget, we now need to know the width of the Eigentarget so that we can deconvolve it with the raw data and find the MTF of the SUT. Without getting into a rigorous proof, it can be shown that the only square wave which would satisfy the symmetrical concavity noted above would be one of exactly 1/2 the width of the triangle wave which would describe the response of the SUT. This implies that the width of the actual response of the system is 2/3 of the width of the measured response.

2.2. SCALING THE SINC-SQUARED FUNCTION

At this point we have all of the information we need to compute the MTF of the system. The first null of the sinc-square can be found by setting the argument of equation (3) equal to π :

$$MTF = \text{sinc}^2\left(v \frac{\Gamma_a}{4}\right) \quad (3)$$

Where:

v is a variable in spatial frequency, and

Γ_a is the width of the actual spatial response of the system.

Substituting:

$$\Gamma_a = \frac{2}{3} \Gamma_m \quad (4)$$

Where:

Γ_m is the width of the measured response of the SUT.

and then by substituting:

$$2\pi f \cdot v \quad (5)$$

Yields the first null of the sinc-square to be:

$$f_n = \frac{3}{\Gamma_m} \quad (6)$$

in the pixel frequency domain.

We can now move on to the general case which does not assume the system MTF to be a sinc-squared function. Given that the measured data defines a function in the space or pixel domain (x) which is of some finite width, the solution takes the form of:

$$\text{MTF} = \frac{S[f_m(x)]}{\text{sinc}(\sqrt{\frac{\Gamma_m}{6}})} \quad (7)$$

2. 3. RECONCILING CALCULATED VERSUS OBSERVED RESOLUTION DATA

In order to convert to spatial frequency domain, we only need to know the angular subtense of a pixel. This can be found through any one of several methods. For example, in a lab test, by knowing the dimensions of the target used and the focal length of the collimator one can determine the angular subtense simply by division. While equation (6) identifies the first null of the system MTF, conventional tests report on the highest spatial frequency which can be resolved by a trained observer. In an effort to correlate the implications of equation (6) toward predicting what a human observer would see, we must look further into the data. The question then becomes; what is happening geometrically at the first null? At that spatial frequency, the optical limits as well as the pixelation process combine such that no spatial modulation is passed through the system. For the pixel limited condition this would equate to a single pixel and its contiguous neighbors subtending both state 1 and state 2 equally. For the diffraction limited case, blurring occurs such that the two states would symmetrically overlap. Each condition implies that modulation of 1/2 the spatial frequency found in equation (6) could be taken as the limiting spatial frequency in that that spatial frequency could be faithfully passed through the system without aliasing.

3. RESULTS FROM ACTUAL TESTS

Data was collected on several different systems including night vision goggles, visible light reconnaissance sensors and a CCD. The results from operating on imagery as described in this paper and resolution results obtained by observation are listed and compared in Table I.

4. CONCLUSIONS

As Table I suggests, a reasonable correlation exists between the observed resolutions of the various systems and those predicted by the Eigentarget method. The arbitrarily chosen predicted spatial frequency of $\frac{1}{2}$ that of the null and the subjective observations of the observer may account for the discrepancies between the observed and predicted values. In any case, this approach represents a viable candidate for a new metric for testing imaging systems in the field. The repeatability and objectivity of this analysis appears to have great potential utility. The test process itself could be significantly streamlined through the anticipation of the Eigentarget analysis process.

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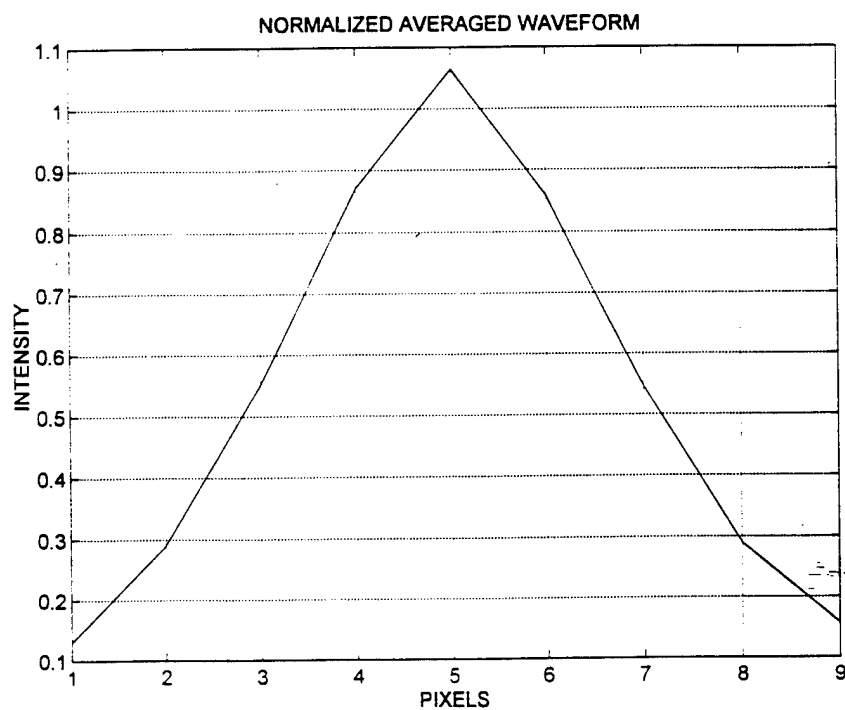


Figure 1

SENSOR TYPE	TARGET ANGULAR SUBTENSE (c/mrad)	# PIXELS SUBTENDED	PIXEL ANGULAR SUBTENSE (mrad)	MEASURED RESPONSE (pixels)	RESOLUTION CALCULATED (c/mrad)	RESOLUTION OBSERVED (c/mrad)
RECONNAISSANCE	1.008	33	0.031	7	7	10
RECONNAISSANCE	0.504	15	0.034	9	4.96	5.64
NIGHT VISION	0.191	19	0.275	7	0.77	0.606-0.764
NIGHT VISION	0.107	33	0.283	11	0.49	0.606-0.680
CCD	0.107	60	0.156	9	1.07	1.36

Table I
Test Data